LA-UR-80-2574

MASTER

TITLE: A STUDY ON THE USE OF ADAPTIVE CONTROL FOR ENERGY CONSERVATION IN LARGE SOLAR HEATED AND COOLED BUILDINGS

AUTHOR(S): Donald R. Farris
James L. Melsa

SUBMITTED TO: 19th IEEE Conference on Decision and Control
Albuquerque, New Mexico
December 10-12, 1980

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

Form No. 836
St. No. 2629
1/75

UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

A STUDY ON THE USE OF ADAPTIVE CONTROL FOR ENERGY CONSERVATION IN LARGE SOLAR HEATED AND COOLED BUILDINGS*

Donald R. Farris**
Los Alamos Scientific Laboratory
University of California
P. O. Box 1663, MS 429
Los Alamos, NM 87545

James L. Melsa
Department of Electrical Engineering
University of Notre Dame
Notre Dame, IN 40556

Introduction

Since 1976, personnel at the Los Alamos Scientific Laboratory (LASL) have been studying the use of adaptive and optimal control techniques in solar heated and cooled buildings. This study has led to the development of a specific systems approach designated as adaptive optimal control (AOC). In this study, theoretical and computer simulation studies using the AOC concept indicate that substantial energy savings can be realized. As the AOC concept has been refined, it has enjoyed increased confidence in its ability to improve energy conservation and system performance. Various stages of development have produced simulations with substantial auxiliary (back-up) energy savings over the conventional controller simulation for the system. Other experiments in optimizing the control strategies in the solar heated and cooled Los Alamos National Security and Resources Study Center (NSRSC) demonstrate emphatically that a considerable amount of energy can be saved by modifying conventional control hardware, and most importantly, by reviewing the control function from a system level.

Simulation Model

The NSRSC at LASL provides the basis for a general model used in this simulation. The NSRSC is a 59,000 ft^2 library and conference facility. It has both solar heating and cooling systems, but only the heating system is discussed here.

A simplified model of the solar heating system for the building is used. A schematic for the system is shown in Fig. 1. The system model contains a solar collector, a collector coolant loop, and a one-node storage tank.

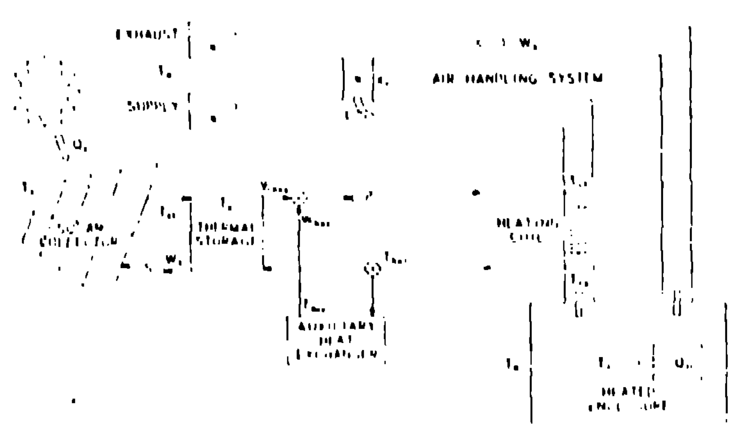

Fig. 1. Solar heating systems model.

* This work has been supported by the Solar Heating and Cooling Research and Development Branch, Office of Conservation and Solar Applications, US Department of Energy.

** Presently with the Department of Electrical Engineering, University of Evansville, P. O. Box 329, Evansville, IN 47702.

Auxiliary energy is provided by a steam-to-water heat exchanger, and the steam is supplied by a central steam plant. The hot water flows through coils in the air duct to heat the air flowing over them. The heated space in the building is represented by a single enclosure. The air-handling system provides air movement and a capability for recirculation of some of the partially conditioned air and introduces fresh air as appropriate.

Solution Technique

The AOC technique can be explained with the system block diagram of Fig. 2. The building (plant) represents the nonlinear dynamics of the building and entire heating, ventilating, and air-conditioning (HVAC) system. As control and exogenous disturbances (e.g., outside temperature) are applied in time, the dynamic building responds and the state of the building results. The applied control, the exogenous inputs, and the building state are measured as functions of time. These measured values are then used by the model identification block to estimate the parameters for a linearized system using a sequential least squares approach. This linearized system is valid only in a region about the operating point, so a subsequent estimation of the parameters will be needed when the operating point changes significantly.

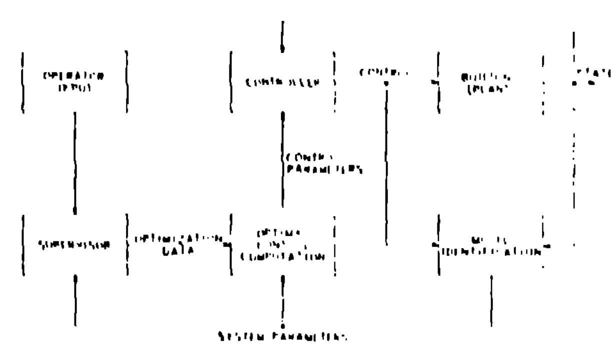

Fig. 2. System block diagram.

The linearized system parameters are then used by the optimal control computation block to determine the control parameters. The optimal control computation uses a linear regulator solution whose performance index terms include deviations of room temperature from a set point and use of auxiliary energy. Because some of the tradeoff parameters in the performance index may change with successive optimization computations (e.g., the performance penalty for room temperature deviations might be relaxed at night), optimization data are supplied by the supervisor block. The supervisor also provides a channel for the human building operator to communicate data to the system.

The optimal control computation produces the control parameters (gains, offsets) that are used by the controller to implement the closed-loop control. The building then operates with this optimal control for a period of time that would probably not exceed 15 min, and the process of model identification, optimal control computation, and controller implementation repeats itself The AOC system is thus updated or adapted to remain optimal as the system undergoes changes of various forms.

Simulation Results

This investigation of the use of adaptive control concepts began with the definition of the HVAC system model to be used for simulation studies. Building operation was simulated under control of a conventional controller that embodies current strategies and under control of an AOC controller, and system performances were compared. Both controllers maintained the room temperature quite well. The AOC controller, however, did so with significantly less auxiliary energy. Depending on simulation conditions the AOC auxiliary energy savings over the conventional controller were as high as 51% for a 2-day simulation and 95% for a month-long simulation.

It must be remembered that these are savings in auxiliary, or back-up, energy that is used when the solar energy system cannot meet the heating or air-conditioning demands alone. When comparing controllers as we have, a claim of 100% savings in auxiliary energy means that the claiming controller is able to operate the solar energy system to meet the heating demand without any back-up.

The question of how the AOC controller is able to achieve these savings in auxiliary energy remains. The answer is that the AOC controller provides better management of the available sources of energy. In the 2-day simulation that saved 51% of the auxiliary energy, the weather was sunny and very cold; and the AOC controller operated the storage tank at a lower temperature. This improved utilization of solar energy, and as a serendipitous benefit, it made collection of solar energy more efficient. In the month-long simulation the weather varied, but was generally milder. One aspect of the AOC controller's management of the building here is that the air-handling system was controlled to exhaust much less heated air to the outside. To illustrate, the AOC controller exhausted about 2,500,000 fewer Btu than the conventional controller. The reduction in auxiliary energy use was about 1,250,000 Btu and the reduction in solar energy use was about 1,270,000 Btu.

The complexity of large solar HVAC systems generates many sets of conditions for the controller to handle. The best operating strategies are not completely understood and, perhaps more important, they vary from one set of conditions to another as the above simulations indicate. The AOC technique has the power to examine those conditions on a regular basis (several times each hour), determine the best strategy at the moment, and implement the control automatically.

Implementation

Implementation has been studied,[1] and it is felt that the AOC techniques can be implemented as a prototype with hardware similar in capability to minicomputer-based building energy-management system like those commercially available. It is further felt that commercial AOC products may be realized with microprocessors and offer an attractive pay-back period.

Plans have been made for implementation of a prototype AOC system in the NSRSC at LASL, and funding for the implementation is being investigated.

References

Space does not permit a comprehensive list of publications and references, and the reader is referred to [2-3].

1. Farris, D.R. and J. L. Melsa, "A Study on the Use of Adaptive Control for Energy Conservation in Large Solar Heated and Cooled Buildings," Proc. The 19th IEEE Conference on Decision and Control, December 1980.

2. Farris, D.R. and T.E. McDonald, "Adaptive Optimal Control--An Algorithm for Direct Digital Control," ASHRAE Transactions 1980, Vol. 86, Part 1, February 1980.

3. Farris, D.R. "Adaptive Control for Energy Conservation," Proc. Department of Energy Active Solar Heating and Cooling Contractors' Review Meeting, March 1980.